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THE CLASSIFICATION OF IGNEOUS INTRUSIVE BODIES[1]

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THE NEED FOR A CLASSIFICATION

At the present time geological science is engaged with no general question more widely and thoroughly discussed than that of the origin of the igneous rocks. The elaborate chemical studies of those rocks, the many new classifications of rock species, the modern experiments in the synthesis of natural silicates, and the experiments on the physical and chemical properties of molten silicates, have as their chief end the demonstration of the facts upon which a stable theory of rock genesis can be founded.

All such studies must be pursued with constant reference to the actual occurrences of igneous rocks in nature. Petrology is dependent upon, knit together with, field geology; the heart of geological philosophy is petrology in its broad sense. On the chemical side the laboratory observations of rock-analysts have been rated as "superior" (excellent, fair, or good) or as "inferior" (poor or bad). Similarly, field observations can be rated as superior or inferior according to the fulness and accuracy with which they supply the data from outdoor nature. Of those facts none is of more importance to petrology than the mode of occurrence of igneous rocks.

The field information required for the great group of the igneous intrusives relates to their shapes, sizes, and methods of intrusion. The statement of field facts depends on the precision of the terms used to describe them. That precision depends on definition. Scientific definition necessarily means classification.

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Neither in the definition nor in the classification of igneous intrusive bodies is there at present unanimity or consistency among geologists. The same author defines "dike" or "sheet" or "batholith" in quite different ways on different pages. Of late years "laccolith," "boss," "stock," and practically every other term referring to igneous intrusions, have from different writers respectively received definitions varying in essentials. In several cases the difference of usage has sprung from the subjective influence of theories of intrusion. Some of the most recent definitions of older terms have thus become too intensive in meaning to fill the needs of the great body of field workers who are still in the wholesome attitude of mind that forbids the final adoption of any theory of intrusion for many important igneous bodies.

The writer believes that a comparatively full classification of igneous intrusive bodies is needed. The general adoption of a consistent, well-defined scheme of types—a scheme as complete as possible, but elastic enough to permit of new types—would tend to make field descriptions more scientific than many of them are at present. Such general adoption would mean a gain in precision, the soul of scientific writing; a gain in the ease with which a paper descriptive of igneous intrusions would be understood; and an economy of words induced by the employment of terms of definite, precise meaning. The filling-out of the scheme of classification to an extent quite beyond that now prevailing in standard text-books of geology should further have the effect of sharpening the eyes of the field observer. He may perhaps not be content to describe a given granite intrusion as simply a "mass," or an "area," or an "outcrop," if it be possible by the study of its contents to indicate the real form and relations of the granite body. The use of the term "mass" in that sense is often excellent because of the apparent impossibility of determining the true shape of the granite body; but such justifiable employment of the term implies that that particular body cannot as yet be thoroughly classified. A rather negative name has in such a case a distinct value. Of yet greater value is the positive reference of intrusive bodies to definite categories. A good observer always feels the pressure of the category. If his classification be systematic, his observing power is quickened, his report enriched; if his classification be that in general use, his descriptions will be of the greater service to the science.

The purpose of this paper is to present certain of the current definitions and classifications of intrusive bodies; from the definitions and classifications to attempt the deduction of the various principles underlying them; and, finally, to offer for discussion a classification which shall aim at a systematic and consistent use of the principles which seem best adapted to the case. As far as possible, these principles are the same as those already in common use among leading geologists.

FORMER CLASSIFICATIONS

A few representative classifications of igneous intrusive bodies will serve to show the range of types recognized by recent authors.

I. Sir Archibald Geikie, *Text-book of Geology* (4th ed., 1903), Vol. II, p. 722:
  1. Bosses (stocks).
  2. Sills, intrusive sheets.
     Variety: laccolith.
  3. Veins and dykes.
     Varieties: contemporaneous veins, segregation veins, multiple dykes, compound dykes.
  4. Necks.

II. T. C. Chamberlin and R. D. Salisbury, *Geology* (1904), Vol. I., pp. 476, 477:
  1. Dikes.
  2. Necks or plugs.
  3. Sills.
  4. Laccoliths.
  5. Bysmaliths.
  6. Bathyliths.

III. F. Zirkel, *Lehrbuch der Petrographie* (1893), Vol. I, p. 539:
  1. Gänge.
  2. Lagergänge.
  3. Gangstöcke.
  4. Apophysen.
  5. Stöcke.
  6. Intrusivlager.
  7. Lakkolithen.

DEFINITION OF TERMS DESCRIPTIVE OF INTRUSIVE BODIES

Dike.—The best established of all the terms used in the foregoing lists is "dike;" yet the variation in even recent definitions of it is apparent in such examples as the following:

I. G. K. Gilbert:[1]

> Dikes differ from sheets in that they intersect the sedimentary strata at greater or less angles, occupying fissures produced by the rupture of the strata.

II. G. P. Merrill:[2]

> A dike: "an eruptive mass of varying width included between well-defined walls, and occupying a fissure or fault in previously consolidated rocks. Such are inclined at all angles with the horizon, and are usually of very moderate width, but may extend for miles."

III. T. A. Jaggar:[3]

> A dike is an elongate intrusive igneous body occupying a fissure in any sort of rock, the walls of which at the time of intrusion were vertical or, if inclined, at angles nearer the vertical than the horizontal. A dike must have longitudinal extension much greater than its breadth, but may vary in thickness from an inch to several hundred feet. A dike may be irregular or may follow a sinuous course; it may be intruded between the beds of vertical or steeply inclined sediments; it frequently follows joint surfaces and has smooth and plane bounding walls. It must be noted that a flat igneous mass intruded between horizontal or nearly horizontal strata, and subsequently upturned with them to a vertical position, is not a dike, but a sill.

IV. Sir Archibald Geikie:[4]

> Dykes are veins of eruptive rock, filling vertical or highly inclined fissures, and are so named on account of their resemblance to walls (Scotice, dykes).

V. T. C. Chamberlin and R. D. Salisbury:[5]

> When lava is forced into crevices or rises to the surface through fissures, and the residual portion solidifies in them, it gives rise to dikes.

All the foregoing definitions agree in ascribing to a dike the characteristic form of a fissure-filling. Gilbert, in the quotation; Geikie, and Chamberlin and Salisbury, in their respective contexts, expressly exclude from the category of dikes all sheetlike intrusions thrust into the bedding-planes of stratified formations, whatever is or has been the angle of dip. The same usage appears in the writings of most field geologists, whether English-speaking or not. Geikie emphasizes the generality (necessity?) of high angles of dip in true dikes. Jaggar makes the angle of dip at the time of intrusion the principal criterion in distinguishing dikes from sills, and advocates a definition of both dike and sill which is not followed by the great majority of geologists. J. D. Dana[1] states that dikes may vary "in position from vertical to horizontal," and it is seen that Gilbert's and Merrill's definitions agree with that usage of the term. Since most dikes are nearly or quite vertical, the difficulty of classifying those eruptive fissure-fillings which lie nearer horizontal than vertical planes has not often been mentioned in geological literature.

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[1] *Geology of the Henry Mountains* (1877), p. 20.

[2] *Rocks, Rock Weathering and Soils* (1897), p. 50.

[3] *Twenty-first Annual Report of the U. S. Geological Survey*, Part 3 (1901), p. 172.

[4] *Text-book of Geology* (4th ed., 1903), Vol. II, p. 743.

[5] *Geology* (1904), Vol. I, p. 476.

Most geologists are thus agreed that dikes in stratified formations are bodies always cross-cutting the bedding planes. Many geologists agree that the angle of dip is immaterial. All agree as to the criterion of form, namely, that of a fissure-filling narrow in proportion to its length and bounded by parallel or nearly parallel walls of country rock.

According to the commonest and best usage, an igneous dike (*a*) is an injected body, (*b*) has nearly or quite parallel walls, (*c*) is narrow in proportion to its outcropping edge, (*d*) cuts across the bedding when the invaded formation is stratified, and (*e*) has any angle of dip.

When stratification and cleavage or schistosity are not coincident, such an intrusive body is generally called a dike, even though it follows the planes of cleavage or schistosity. This usage will be adopted in the classification proposed in this paper.

Multiple dikes are compound intrusions of dike form, due to successive injections of homogeneous material on the same fissure.[2] For illustrations, see Harker, *Tertiary Igneous Rocks of Skye*, pp. 296–304; A. Geikie, *Ancient Volcanoes*, Vol. II, p. 417.

Composite dikes are compound intrusions of dike form, due to successive injections of different materials into the same fissure.[3]

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[1] *Manual of Geology*, 4th ed., 1895, p. 298.

[2] Geikie, *Text-book of Geology*, Vol. II, p. 746.

[3] J. W. Judd, *Quarterly Journal of the Geological Society*, London, Vol. XLIX (1893), p. 536; A. Harker, *Tertiary Igneous Rocks of Skye* ("Memoirs of the Geological Survey of Great Britain," 1904), p. 197.

A. Geikie has used "compound" in the sense of "composite" in the foregoing definition;[1] Lawson has used "multiple" with the same meaning. The nomenclature given in the above definitions is preferred, as it brings out the analogy with "multiple" and "composite" sills and laccoliths—types already well named and established.

A composite dike is illustrated in Fig. 1.

A *dike network* is a reticulate group of dikes simultaneously injected. For illustration see *Bulletin No. 209*, U. S. Geological Survey, 1903, section, Plate 7.

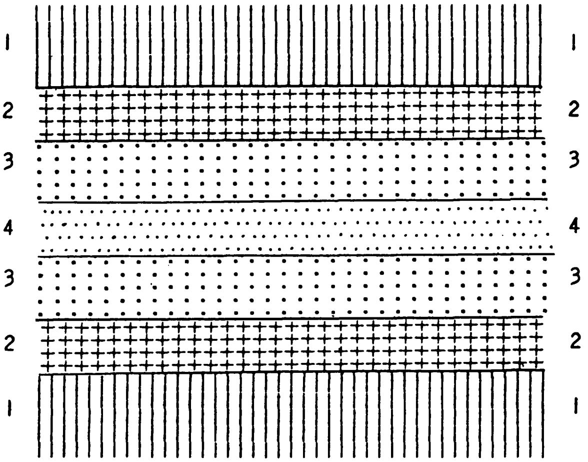

FIG. 1

Intrusive vein.

I. J. B. Jukes:[2]

> When the injected mass has arisen along an opened fissure, and solidified there as a wall-like intrusion, it is called a *dyke*. When its path has been less regularly defined, and penetrates the surrounding rocks in a wavy thread-like fashion, this irregular protrusion is called a *vein*.

II. A. Geikie:[3]

> *Veins* have been injected into irregular branching cracks.

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[1] *Text-book*, Vol. II, p. 746.

[2] *Manual of Geology*, edited by A. Geikie (1872), p. 263.

[3] *Text-book* (1903), p. 744.

Contemporaneous vein.

> Forms part of the igneous rock in which it occurs, but belongs to a later period of consolidation than the portion into which it has been injected.[1]

Apophyses or tongues are dikes or veins which, either directly or by inference from field relations, can be traced to larger intrusive bodies as the source of magmatic supply for dike or vein.[2]

Intrusive sheet.—This familiar expression has generally been defined as equivalent in meaning to "sill."[3] It may well be extended to cover the case of an igneous layer injected on a plane of unconformity in stratified formations, when the igneous layer is thus sensibly parallel to the bedding-planes of one of the stratified formations. This type, for lack of a better term, may be called an *interformational sheet.* For illustration of such a sheet on a colossal scale, see "Map of Northern Nickel Range," Sudbury District, Ontario, by A. P. Coleman.[4]

Sill.

I. A. Geikie:[5]

> A *sill* is a sheet of igneous material which has been injected into a sedimentary series and has solidified there, so as to appear more or less regularly intercalated between the strata.[6]

II. T. A. Jaggar.[7]

> A sill is an intrusive sheet forced between strata which are horizontal or which, if tilted, lie at angles more nearly horizontal than vertical. . . . . Transitions between dike and sill occur when a sill breaks upward at an angle of 45°, or when a dike follows the bedding-planes of strata inclined at that angle.

III. Chamberlin and Salisbury:[8]

> If the lava is forced between beds of rock in the form of a sheet, and solidifies there, it is called a *sill.*

The definition of I and III is that which is adopted by nearly all authors writing in English on this type of intrusive body. The term "sill" has also its equivalents in this sense in other languages. Definition II is not only contrary to general usage but suffers from special imperfections due to the artificial nature of the chief criterion distinguishing dike and sill. (Compare Definition III of "dike.") Among those imperfections is the difficulty of classifying by Definition II many intercalated sheets now dipping at high angles, for with them it may be impossible to say what were their original dips.

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[1] Geikie, *op. cit.*, p. 738.

[2] See A. Geikie, *Quarterly Journal of the Geological Society*, Vol. L (1894), p. 222, and *Ancient Volcanoes of Great Britain*, Vol. II (1897), p. 439.

[3] E. g., Jukes, *Manual*, p. 254; Gilbert, *op. cit.*, p. 20; Iddings, *Twelfth Annual Report of the U. S. Geological Survey*, Part 1, p. 578; Geikie, *Text-book*, p. 732.

[4] *Report of the Bureau of Mines*, Ontario, 1904.

[5] *Geology of Eastern Fife* ("Memoirs of the Geological Survey of Scotland," 1902), p. 189.

[6] Cf Geikie, *Text-book*, p. 732.

[7] *Op. cit.*, p. 172.

[8] *Op. cit.*, p. 476.

It thus seems best to adhere to the prevailing use of the term "sill" in a systematic classification of intrusive bodies. A sill may be of great thickness, as illustrated on Fig. 2, but it is necessary that the sheet shall hold its thickness for considerable distances along its outcropping edge.

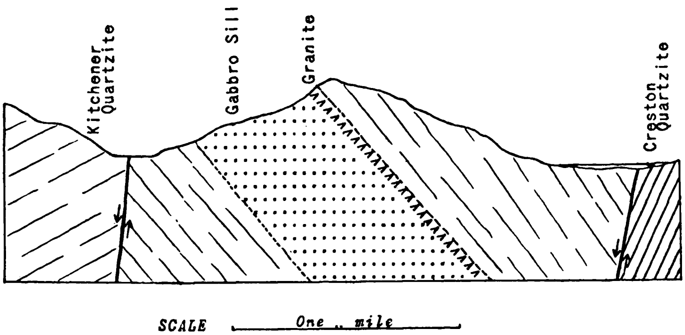

FIG. 2

A *multiple sill* is a compound intrusion of sill form and relations, and is the result of successive injections of one kind of magma along a bedding-plane in a stratified formation.[1] For a remarkable illustration, see Harker.[2]

A *composite sill* is a compound intrusion of sill form and relations, and is the result of successive injections of more than one kind of magma along a bedding-plane in a stratified formation.[3]

A section of a composite sill is illustrated in Fig. 3.

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[1] See A. Geikie, *Ancient Volcanoes of Great Britain*, Vol. II, pp. 318 ff.; and especially A. Harker, *op. cit.*, p. 197.

[2] *Op. cit.*, p. 239.

[3] See Harker and Geikie, same pages as noted for multiple sills.

Laccolith.—Divergence of definition and usage becomes very marked in the case of the term "laccolith."

I. The original definition by G. K. Gilbert:

> The station of the laccolite being decided, the first step in its formation is the intrusion along a parting of strata, of a thin sheet of lava, which spreads until it has an area adequate, on the principle of the hydrostatic press, to the deformation of the covering strata. The spreading sheet always extends itself in the direction of least resistance, and, if the resistances are equal on all sides, takes a circular form. So soon as the lava can uparch the strata, it does so, and the sheet becomes a laccolite. With the continued addition of lava, the laccolite grows in height and width, until finally the supply of material or the propelling force so far diminishes that the lava clogs by congelation in its conduit and the inflow stops.[1]

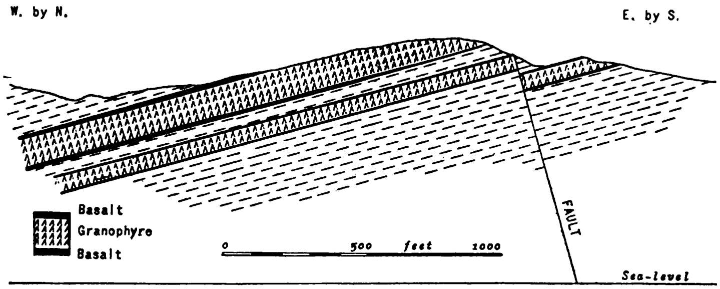

FIG. 3

> As a rule, laccolites are compact in form. The base, which in eleven localities was seen in section, was found flat, except where it copied the curvature of some inferior arch. Wherever the ground plan could be observed, it was found to be a short oval, the ratio of the two diameters not exceeding that of three to two. Where the profile could be observed, it was usually found to be a simple curve, convex upward, but in a few cases, and especially in that of the Marvine laccolite, the upper surface undulates. The height is never more than one-third of the width, but is frequently much less, and the average ratio of all the measurements I am able to combine is one to seven.
>
> The ground plan approximates a circle, and the type form is probably a solid of revolution—such as the half of an oblate spheroid.[2]
>
> The laccolite is a greatly thickened sheet [sill] and the sheet [sill] is a broad, thin, attenuated laccolite.[3]
>
> The laccolite in its formation is constantly solving a problem of "least force," and its form is a result. . . . . A laccolite grows "by lifting its cover."[4]

The clearness and precision of Gilbert's description gives a distinct and unmistakable individuality to his original type. It is a greatly thickened sill of compact, domical form, with (*a*) a limital thickness, (*b*) a limital area, (*c*) a flat base, (*d*) an oval or circular ground plan, and (*e*) a specialized method of intrusion, namely, by lifting a stratified cover which thus assumes a dome structure.

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[1] *Op. cit.* (1877), p. 95. [2] *Ibid.*, p. 55. [3] *Ibid.*, p. 20. [4] *Ibid.*, p. 91.

Gilbert notes, as a first variation on the simple type, a compound type of laccolith which is "built up of distinct layers. . . . . It is probable that all the larger laccolites are composite, having been built up by the accession of a number of distinct intrusions."[1]

He continues:

> If the strata had experienced anterior displacements so as to be inclined, folded, and faulted, a symmetrical growth of laccolites would have been impossible, and the mountains would not have yielded a knowledge of the type form. But the type form being known, it is to be anticipated that in disturbed regions aberrant forms will be recognized and referred to the type.[2]

II. Cross[3] illustrates many examples of true laccoliths which show aberrant forms in just such a way as was foretold by Gilbert. Cross still holds that the body is a laccolith even if its expansion has taken place from a plane only approximately parallel to the bedding of the invaded strata. He emphasizes the asymmetric dome as more nearly the real shape of a laccolith in nature, and attributes such irregularity of form chiefly to lines of weakness existing in the sedimentary formation before intrusion took place. A more fundamental difference between the definitions of Gilbert and Cross appears in their respective statements as to the method of intrusion. Cross holds that the deformation of the stratified cover is in many cases not simply due to the force of a gigantic hydrostatic press; that the deformation was then incidental to the gaping of strata undergoing lateral, orogenic pressure, the magma being more or less passive as it was injected.

III. Weed and Pirsson[4] agree with the views of Cross, but Pirsson returns to the idea of the hydrostatic press as explanatory of the intrusions in the Judith Mountains. Both authors consider that a horizontal base is not necessary for a true laccolith, and that some laccoliths are doubly convex.

[1] *Op. cit.*, p. 55.

[2] *Ibid.*, p. 98.

[3] *Fourteenth Annual Report*, U. S. Geological Survey, Part 2 (1894), pp. 184 ff.

[4] *Eighteenth Annual Report*, U. S. Geological Survey, Part 3 (1898), p. 581.

IV. Jaggar[1] found that the laccoliths of the Black Hills illustrated conclusions essentially equivalent to those of Cross, states his belief that the magmas were mostly passive during intrusion, the laccolith chambers being opened by orogenic stresses, and remarks that laccoliths may be doubly convex.

V. The recent definition of Chamberlin and Salisbury[2] returns once more to the original type of Gilbert: "If, after rising to a certain point in the strata, the lava arches the beds above into a dome, and forms a great lens-like or cistern-like mass, it constitutes a *laccolith*."

It is seen that there is considerable diversity of usage for the term "laccolith." On the whole, this diversity is a sign of progress in geological science. Gilbert's ideal type has been supplemented by others that vary from the ideal in one or more particulars, under conditions which Gilbert himself foretold, if it were but in brief expression.

Those who have made actual researches among laccoliths, and have preserved the term "laccolith" with the original meaning of Gilbert's broader definition, are agreed on the following characteristics: (*a*) Whatever the origin of the force involved, a laccolith is always *injected*. (*b*) A laccolith is always in sill-relation to the invaded, stratified, formation; that is, the injection has, in the main, followed a bedding-plane; but, like sills, laccoliths often locally break across the bedding. (*c*) A laccolith has the shape of a plano-convex or doubly-convex lens flattened in the plane of bedding of the invaded formation. The lens may be symmetric or asymmetric in profile, circular, oval, or irregular in ground plan. (*d*) There are all transitions between sills and laccoliths.

For many illustrations of simple symmetric and asymmetric laccoliths, see the cited writings of Gilbert, Cross, Weed and Pirsson, and Jaggar.

Compound laccolith.—In the Judith Mountain type, as in the larger examples of laccoliths in the Henry Mountains, the whole intrusive body is divided by strong beds of the invaded formation. This gives the appearance of a number of distinct intrusions, one of them dominating, the others subsidiary, in size, but all of them composed of the same kind of material. If the magma has all been intruded at practically the same time, we have the "compound laccolith" of Weed and Pirsson.[1]

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[1] *Op. cit.*, p. 173.

[2] *Geology*, Vol. I, p. 476.

A *multiple laccolith* may be conceived, the name being formed on the analogy of "multiple dike" and "multiple sill." It would differ from a compound laccolith only in the fact that the deformation of the strata, while again similar in character to that produced during the intrusion of a simple laccolith, has been due to distinctly successive injections of the same kind of magma. This case has not yet been described as actually occurring in nature.

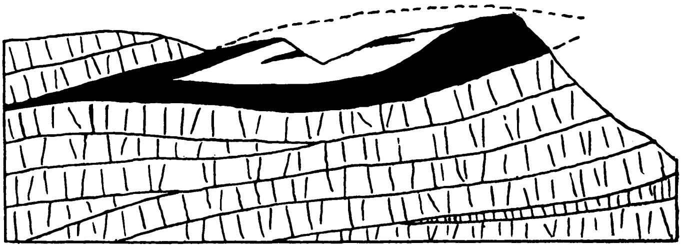

FIG. 4

Composite laccolith.—Harker[2] has noted the occurrence of "composite laccoliths" in the island of Skye. The analogy with composite dike and sill is again perfect. The principal distinction from both compound and multiple laccoliths is found in the heterogeneous nature of the magma successively injected in this last case. (See Fig. 4.)

Interformational laccolith.—Weed and Pirsson[3] have described as a laccolith a great, lenticular mass of porphyry injected along a surface of unconformity, namely, that between pre-Cambrian crystalline schists and a sedimentary Cambrian formation. Such a type is again aberrant from Gilbert's types, but should certainly be classed among the laccoliths; the writer proposes the not altogether satisfactory name "interformational laccolith" for this case. (See Fig. 5, and compare a similar section of an occurrence in the Black Hills of South Dakota, published in the *Annals of the New York Academy of Sciences*, Vol. XII (1899), p. 212.)

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[1] *Op. cit.*, p. 580; see figure.

[2] *Op. cit.*, p. 209.

[3] *Journal of Geology*, Vol. IV (1896), p. 402.

Plug.—Russell has described as "plutonic plugs" certain intrusions occurring in the Black Hills of Dakota. They "are composed of igneous matter forced into sedimentary strata and have a plug-like form."[1] He continues: "How the stratified beds below the domes that covered the plugs were displaced, or perhaps fused, so as to furnish room for the passage of the intruded material, is not clear." Again: "None of the plutonic plugs examined by me are associated with dikes or faults."[2] "They occur in a region where the stratified rock into which they were forced are essentially horizontal."[3]

Since neither the form nor the method of intrusion is clearly indicated, it is difficult to classify "plugs" in Russell's sense. It is to be noted that Jaggar[4] and Iddings[5] interpret some of Russell's original types as true laccoliths. Russell's statement does not make clear the distinction between "plugs" and stocks. The name "plug" has been rather commonly used as alternative with the magmatic filling of a volcanic vent.[6] For these various reasons, "plugs" will not be included in the proposed classification of this paper.

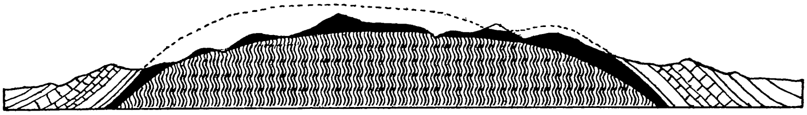

FIG. 5

Bysmaliths.—Allied to "plugs" in Russell's sense is the "bysmalith" of Iddings, described as an injected body filling a "more or less circular cone or cylinder of strata, having the form of a plug, which might be driven out at the surface of the earth, or might terminate in a dome of strata resembling the dome over a laccolith."[7] The downward termination of the original type bysmalith (Mt. Holmes) is found in a hypothetical Archean floor on which the porphyry of the bysmalith rests. See illustrations:[8]

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[1] *Journal of Geology,* Vol. IV (1896), p. 25.

[2] *Ibid.,* p. 42.

[3] *Ibid.,* p. 183.

[4] *Op. cit.,* p. 287.

[5] *Journal of Geology,* Vol. VI (1898), p. 706.

[6] Recently by Merrill, *op. cit.,* p. 51, and by Chamberlin and Salisbury, *op. cit.,* p. 476.

[7] *Monograph No. 32,* Part 2, U. S. Geological Survey (1899), p. 16.

[8] Iddings, *op. cit.,* p. 16; and *Journal of Geology,* Vol. VI (1898), p. 708.

Volcanic neck.—The solid-lava filling of a volcanic vent is evidently intrusive with reference to the formations traversed by the lava, whether those formations are composed of non-volcanic rocks or of agglomerate or tuff which has been pierced by thoroughly molten lava on its way to the surface. (See Fig. 6.)

"*Chonolith.*"—There remains for distinction a class of injected igneous bodies which are not included in any of the above-mentioned categories. In the dislocation of rock formations such as is brought about during mountain-building, actual or potential cavities are formed within the earth's crust. These are commonly filled with igneous magma squeezed into the individual cavity from below, from the side, or, it may be, from above. Dikes, sills, and bodies of laccolithic form (though not strictly of the laccolithic mode of intrusion, as designated by Gilbert) may thus originate. Yet very often the shape of the intruded mass is so irregular, and its relations to the invaded formations so complicated, that the body cannot be classified in any of the divisions so far named. Again, irregular injected bodies of a similarly indefinite variety or form are due to the active crowding-aside and mashing of the country-rock which is forced asunder by the magma under pressure. Or, thirdly, such bodies may be due to a combination of the two primary causes—orogenic stress opening cavities, and hydrostatic or other pressure emanating from the magma itself and widening the cavities.

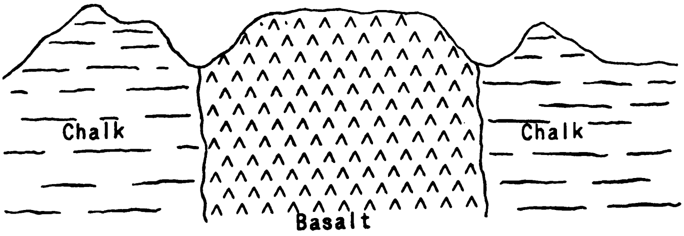

FIG. 6

The number and total volume of these irregular intrusions doubtless greatly exceed the number and volume of all the true laccoliths of the world. In the average mountain range the geologist is more likely to encounter injected bodies of the former kind than he is to discover true laccoliths.

No generally accepted name has yet been proposed for such irregular intrusions. "Laccolith" cannot be used, since that term denotes a definite form, and also implies a special mode of intrusion different from that here conceived. The writer has not been able to find a simple English word for the purpose, and suggests a name formed from the Greek on the analogy of "laccolith," "bysmalith," and "batholith." It is "chonolith," derived from χῶνος, a mold used in the casting of metal, and λίθος a stone. The magma of a "chonolith" fills its chamber after the manner of a metal casting filling the mold. Like a casting, the "chonolith" may have any shape.

A "chonolith" may be thus defined: "an igneous body (*a*) *in*jected into dislocated rock of any kind, stratified or not;[1] (*b*) of shape and relations irregular in the sense that they are not those of a true dike, vein, sheet, laccolith, bysmalith, or neck; and (*c*) composed of magma either passively squeezed into a subterranean orogenic chamber or actively forcing apart the country-rocks.

The chamber of a "chonolith" may be enlarged to a subordinate degree by contact fusion on the walls, or by magmatic "stoping."

An example of a "chonolith" is illustrated in Fig. 7.

Many intrusive bodies that have been mapped and illustrated with sections seem to belong to this same category. Among these may be mentioned a few taken from works dealing with the western Cordillera of the United States.

In the Little Belt Mountains folio of the U. S. Geological Survey, several "stocks" of granite, diorite, etc., are sectioned with relatively narrow feeding channels from below. The Three Forks (Montana) folio contains a map and section of a "laccolith" in non-laccolithic relations. Section "M–M" of the Ten Mile District Special folio shows a mass of granite injected after the manner of a "chonolith." South of Mount Stuart, Washington, the Mount Stuart folio illustrates an irregular intrusion of peridotite with "chonolithic" relations.

Cross[2] states that the intrusive body of Mount Carbon, Colorado, is injected and irregularly cross-cutting; it is not a true laccolith, but appears to be best placed in such a class as that here proposed.

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[1] The term "injected" is used here and elsewhere in this paper in a sense defined in the third paragraph of the following section on the principles of classification.

[2] *Op. cit.*, p. 191.

Weed and Pirsson[1] describe Judith Peak, Montana, as underlain by a "stock" of porphyry. Their section of the "stock" shows, however, a rapid constriction of the body as the section is followed downward. As will be noted on a following page, the section of a true stock typically enlarges downward so that such a body is "subjacent" rather than "injected" with respect to the invaded formations. On the supposition that the section of Weed and Pirsson correctly represents the actual underground relations, the Judith Mountain body has its nearest relatives among "chonoliths" and not among "stocks."

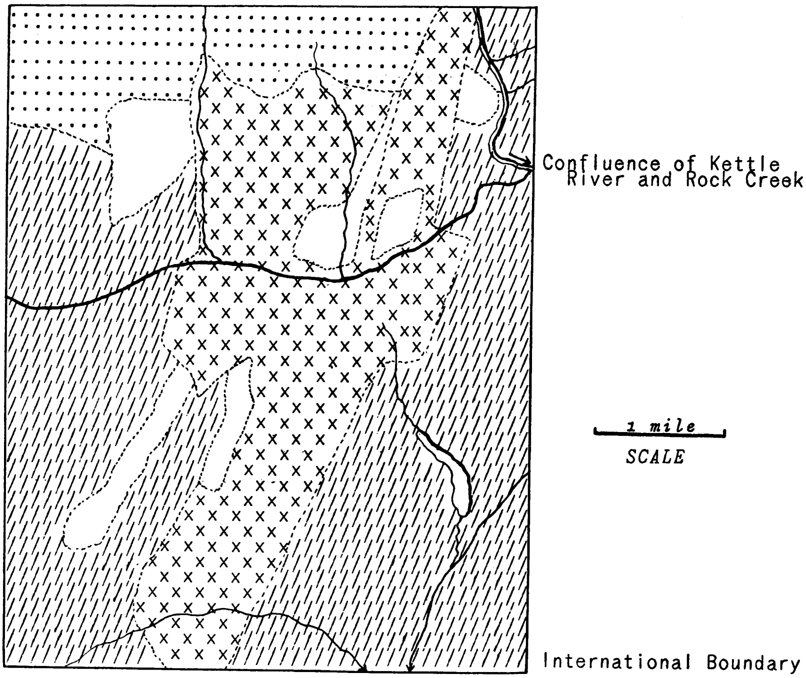

FIG. 7

Jaggar[2] describes the intrusive bodies of Dome Mountain and Whitewood Canyon in the Black Hills as injected bodies of marked irregularity both in shape and in relations to their respective country-rock formations. These bodies seem to be transitional between true laccoliths and typical "chonoliths," but belong to the latter class rather than to the former. Jaggar also describes the "False Bottom Stock" of phonolite in such terms as to lead one to suspect that it may be another, perhaps typical, body of the "chonolith" class.[1]

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[1] *Eighteenth Annual Report*, U. S. Geological Survey, Part 3, 1898, p. 533.

[2] *Op. cit.*, Plates 20 and 21, and pp. 209 and 217.

Jaggar,[2] collaborating with Howe, has experimentally reproduced the conditions under which some "chonoliths" have originated; namely, such bodies as have been injected primarily through the application of force resident in fluid magma under pressure (hydrostatic force). No attempt was made, in their valuable experiments, to imitate injection concomitant with regional deformation.

Whatever may be the validity of any or all of these several cases as illustrations of "chonoliths," there is no question that they can be called "stocks" or "laccoliths," or by any other of the established names, only at the sacrifice of much of the strength, precision, and usefulness of those names. On the other hand, there are thousands of irregular injected bodies which cannot properly be described by the use of any of the established names. It is to be noted, finally, that some such term as "chonolith" may be useful in suggesting the probable nature of an intrusive body in the case where its whole form is not certainly known. The context should then, of course, indicate that the author using the term has in mind only a probability and is making, as it were, simply a report of progress in the description of that particular body.

Boss.—A Geikie[3] defines bosses as

> masses of intrusive rock which form at the surface rounded, craggy, or variously shaped eminences, having a circular, elliptical or irregular ground plan, and descending into the earth with vertical or steeply inclined sides. Sometimes they are seen to have pushed the surrounding rocks aside. In other places they seem to occupy the place of these rocks through which, as it were, an opening has been punched for the reception of the intrusive material. . . . . In true bosses, unlike sills or laccolites, we do not get to any bottom on which the eruptive material rests.

He makes "stock" and "boss" synonymous.

In his *Text-book*[4] Geikie says: "Bosses (stocks) are amorphous masses that have disrupted the rocks through which they rise."[5]

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[1] *Ibid.*, p. 227.

[2] *Ibid.*, p. 302, and Plate 43, section 2.

[3] *Ancient Volcanoes*, Vol. I (1897), p. 88.

[4] Vol. II (1903), p. 722.

[5] Cf. also A. Geikie, *Geology of Eastern Fife* (1902), p. 189.

In English- and German-speaking countries "boss" and "stock" are almost invariably regarded as synonymous, but the latter term has much the greater vogue.[1] The general connotation of the word "boss" seems to warrant the restriction of its meaning so as to include only those stocks which have circular or subcircular ground plans on the surface of exposure. The word has been used to denote intrusions of the sort up to all diameters from a few hundred feet to several miles.

Bosses are "simple" when composed of material intruded in but one period; they are "multiple" or "composite" when composed of material intruded at two or more distinct periods of irruption. The distinction between the latter types is the same as between "multiple" and "composite" stocks.

An illustration of a simple boss is given in Fig. 8.

Stock.—Prevailing usage has fixed the meaning of "stock" as essentially equivalent to Geikie's definition of "boss." A stock is an intrusive body, but is not as clearly *in*jected as is the case with a dike, sill, or laccolith. A stock more or less conspicuously cuts across the structures of the invaded formations; its contacts are, in general, either vertical or highly inclined; its shape is irregular and not determined by planes of bedding or other structures in the country-rocks. It has no visible floor. Van Hise regards a stock as characteristically smaller than a boss,[2] but the present writer has found that general usage does not support that distinction.

Simple stocks are composed of material intruded in one period of irruption.

A *multiple stock* is composed of material demonstrably intruded in two or more periods of irruption, the material having been derived from the same kind of magma.

A *composite stock* is composed of materials demonstrably intruded in two or more periods of irruption, the materials having been originally derived from two or more kinds of magma. (Fig. 8.)

Magmatic differentiation or other influences may render heterogeneous the material composing a simple stock, or each member of either a multiple or a composite stock.

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[1] Cf. Zirkel, *Lehrbuch der Petrographie* (1893), Vol. I, p. 539.

[2] *Monograph No. 47*, U. S. Geological Survey (1904), p. 711.

Batholith.—Suess[1] has finally stated the definition of "batholith" in terms of a theory of intrusion which is at present in discussion. His definition may be freely translated thus: "A batholith is a stock-shaped or shield-shaped mass intruded as the result of fusion of older formations (orig. *Durchschmelzungsmasse*). On the removal of its rock-cover and on continued denudation, this mass either holds its diameter or grows broader to unknown depths (orig. *bis in die ewige Teufe*).[2] The name was invented to describe those largest of all intrusions, generally granitic, which are characteristically found in great mountain ranges; including, thus, "central granites," "intrusive mountain-cores," "Fussgranit," etc. The name has since been commonly used for bodies of intrusive rock with the general characteristics of stocks, but of much larger size than is generally attributed to stocks or bosses. This latter use is, moreover, rarely

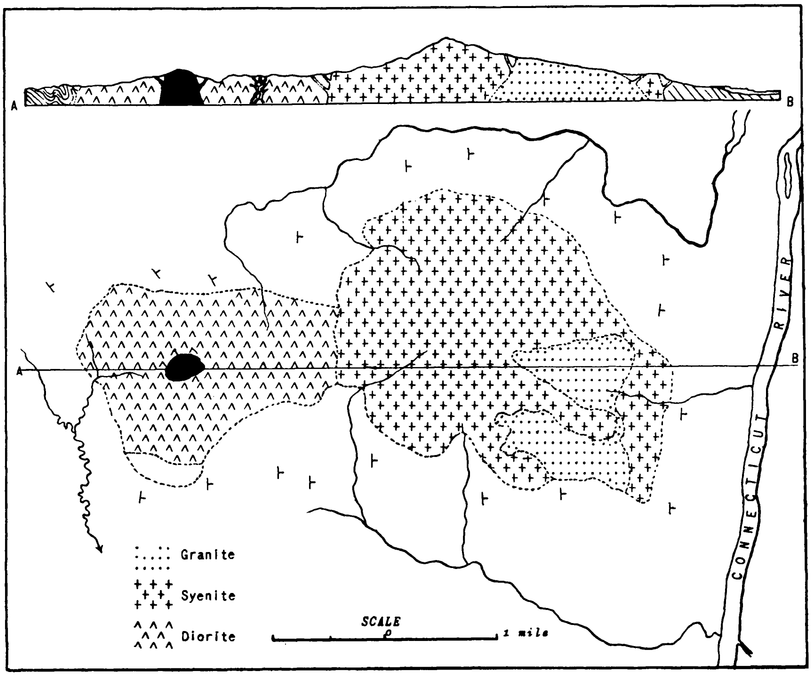

FIG. 8

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[1] *Sitzungsberichte der Wiener Akademie*, Vol. CIV (1895), p. 52.

[2] Compare Chamberlin and Salisbury, *op. cit.*, p. 477; and W. Salomon, Tschermak's *Mineralogische und petrographische Mittheilungen*, Vol. XVII (1897), p. 31.

associated directly with any particular theory of intrusion. There is pressing need for such a term signifying these large bodies, and one that will not commit the field worker to any theory of origins. The later use of the term "batholith" is therefore to be commended, as it renders that term much more useful in actual field descriptions where these cannot be accompanied with certain proofs of the *Durchschmelzung* theory as there applicable. In the proposed classification of intrusives the term "batholith" will have the meaning just noted.

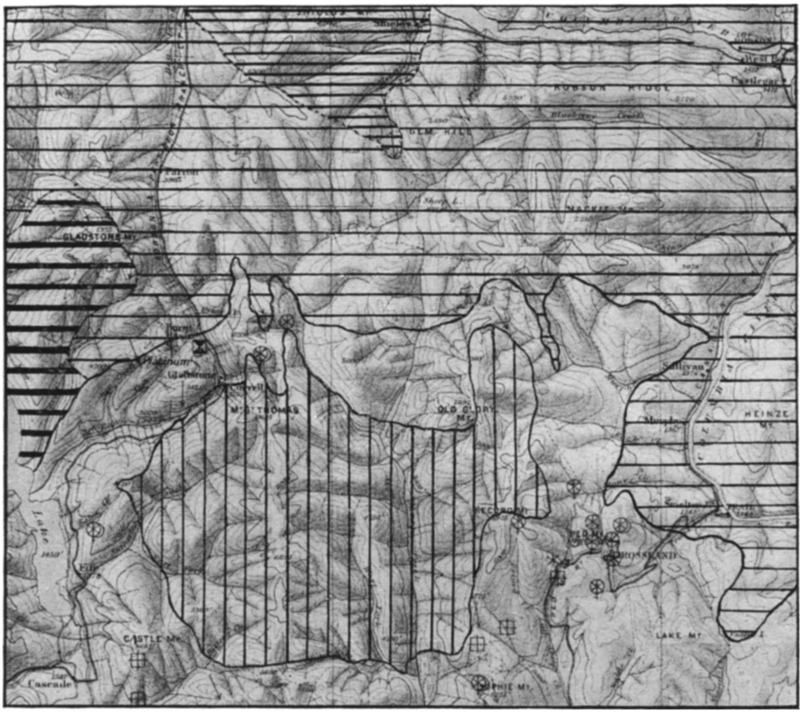

FIG. 9

A *simple batholith* is one composed of material intruded in one period of intrusion. (Fig. 9).

A *multiple batholith* is one composed of material demonstrably intruded in two or more periods of irruption, the material having been derived from the same kind of magma.

A *composite batholith* is one composed of materials demonstrably intruded in two or more periods of irruption, the materials being originally derived from two or more kinds of magma. (Fig. 9.)

A multiple or composite batholith may thus be in part made up of stocks.

Magmatic differentiation or other influences may render heterogeneous the material composing a simple batholith; or each member of a multiple or a composite batholith.

No author has attempted to fix a lower limit to the areal dimensions of a batholith. Since there is no certain distinction either in form or relations between stocks and batholiths, an arbitrary limit may be set between the two on the score of areal extent. It may be proposed that a body of the kind exposed in an area of less than 200 square kilometers is a stock; a similar body with a larger area is, accordingly, a batholith.

PRINCIPLES OF CLASSIFICATION

A review of the foregoing definitions shows that each of them has been based on one or more primary features of igneous intrusions, namely:

a) The method of intrusion.

b) The relation of the body to pre-intrusion structures in the invaded formation.

c) The form of the body.

d) The size of the body.

e) The attitude of the body with reference to the horizontal plane.

For a given body the method of intrusion is the most important criterion that could be used in classification. If it might be determined in every detail just how the igneous mass reached its present position, the form of the body and its relation to structural planes in the country-rock would therewith be known. A genetic, and therefore natural, classification should thus be founded on the method of intrusion. In the present state of geological science it is, however, impossible to apply this fundamental principle throughout the established list of intrusive bodies.

The greater number of recognized types are those of bodies of magma which is exotic except for a small, variable portion of it due to contact fusion. In each of these cases the magma has come into its chamber through channels which have fed the growing body from larger, deeper-lying, generally invisible reservoirs. The chamber is due to a parting of the country-rock into which the magma is *in*jected. An injected body is thus one which is entirely inclosed within the invaded formations, except along the relatively narrow openings to the chamber where the latter has been in communication with the feeding reservoir.

On the other hand, stocks, bosses, and batholiths never show a true floor. They appear to communicate directly with their respective magma reservoirs. Each of these bodies shows field relations suggesting that it is a *part* of its magma reservoir. The communication with the magmatic interior of the earth is not established by narrow openings, but by a huge, downwardly enlarging opening through the country-rock. In relation to the invaded formations a stock, boss, or batholith is intrusive, but is *subjacent* rather than injected.

How a magma reservoir is enlarged by the volume represented in the amount of intrusion signalized on the contacts of stock or batholith is a matter permitting as yet of no absolute certainty. In separating intrusive bodies into two primary divisions, one including all injected bodies, the other including subjacent bodies, a classification will do good service in emphasizing the need of further investigation into the mechanics of intrusion. No one has yet proved that any granite mass over 200 square kilometers in area, and characterized by vertical or outwardly sloping contact surfaces, is due to injection. Whatever may be the probabilities, no one has yet proved that such a mass has been intruded by any kind of assimilation of the invaded formations. Some light has been shed on the origin of batholiths and stocks, but they are certainly not understood as are dikes and sills.

So far as the method of intrusion is concerned, therefore, stocks, bosses, and batholiths belong to a primary division of intrusive bodies which may be defined as not demonstrably due to injection. The principle is negative; it leaves the method of intrusion unstated, but it brings into clear relief a principal contrast subsisting between the greatest of intrusions, on the one hand, and dikes, sheets, laccoliths, etc., on the other.

The other principles of classification—viz., *b*), *c*), *d*), and *e*)—are applied in the classification now to be presented in a manner sufficiently obvious to need no discussion. Principle *e*) is less fundamental than the others, excepting *d*,) and is recognized as appearing only occasionally in the scheme: the major diameters of true laccoliths tend to horizontality; a principal axis of a bysmalith, neck, stock, boss, or batholith is characteristically vertical.

It is obvious that transitional forms are to be expected among the related types of the classification. These forms have not been mentioned in the table, which would thus have become overburdened. Magmatic differentiation within the chambers of dikes, sills, stocks, etc., has often produced varietal types of these bodies, but the process has occurred too irregularly to permit of its furnishing a convenient criterion for the general classification.

PROPOSED CLASSIFICATION OF IGNEOUS INTRUSIVE BODIES

A. *Masses due to injection of exotic material.*
- I. *Injection along planes of stratification in invaded formation.*
  - 1. Intrusive sheets.
    - *a*) Sills.
      - (1) Simple.
      - (2) Multiple.
      - (3) Composite.
    - *b*) Interformational sheets.
  - 2. Laccoliths.
      - (1) Simple.
        - Symmetric.
        - Asymmetric.
      - (2) Compound.
      - (3) Multiple.
      - (4) Composite.
      - (5) Interformational.
- II. *Injection across planes of stratification in invaded formation.*
  - 1. Dikes.
      - (1) Simple.
        - Dike-networks.
      - (2) Multiple.
      - (3) Composite.
  - 2. Eruptive veins.
    - Contemporaneous veins.
  - 3. Apophyses or tongues.

- 4. Bysmaliths.
- 5. Necks.
- 6. "Chonoliths."

B. *Masses due to processes other than injection; subjacent bodies.*

- 1. Stocks and bosses.
    - (1) Simple.
    - (2) Multiple.
    - (3) Composite.
- 2. Batholiths.
    - (1) Simple.
    - (2) Multiple.
    - (3) Composite.